

Environmental Chemicals and Changes in Sex Ratio: Analysis Over 250 Years in Finland

Terttu Vartiainen,^{1,2} Leena Kartovaara,³ and Jouko Tuomisto^{4,5}

¹National Public Health Institute, Department of Environmental Hygiene, Kuopio, Finland; ²Department of Environmental Sciences, University of Kuopio, Kuopio, Finland; ³Statistics Finland, Population Statistics, Helsinki, Finland; ⁴National Public Health Institute, Department of Environmental Medicine, Kuopio, Finland; ⁵Department of Public Health and Community Medicine, University of Kuopio, Kuopio, Finland

It has been proposed that environmental chemicalization is responsible for the recent decline in male ratio, but these speculations are based on statistics going back only a few decades. The objective of this study was to evaluate whether Finnish long-term data are compatible with the hypothesis that the decrease in the ratio of male to female births in industrial countries is caused by environmental factors. We analyzed the sex ratio of births from the files of Statistics Finland and all live births in Finland from 1751 to 1997. Running averages of 9 years (1751–1904) or 5 years (1905–1997) were analyzed for sex ratios. Additionally, to identify potential explanations for the findings, births from 1990 to 1997 were correlated with various family parameters. We found an increase in the proportion of males from 1751 to 1920; this was followed by a decrease and interrupted by peaks in births of males during and after World War I and World War II. None of the family parameters (paternal age, maternal age, age difference of parents, birth order) could explain the time trends. The turning point of male proportion precedes the period of industrialization or the introduction of pesticides or hormonal drugs, rendering a causal association unlikely. Moreover the trends are similar to those observed in other countries with worse pollution and much greater pesticide use. **Key words:** chemicalization, dioxins, male proportion, pesticides, pollution, polychlorinated biphenyls, sex ratio. *Environ Health Perspect* 107:813–815 (1999). [Online 1 September 1999]
<http://ehpnet1.niehs.nih.gov/docs/1999/107p813-815vartiainen/abstract.html>

The proportion of male to female births has been a focus of interest for several reasons. It has been proposed that reproduction hazards attributable to environmental estrogens are responsible for the recent decline in the male ratio (1,2), although these speculations have been based on statistics going back only a few decades. Other factors previously reported to affect the male to female ratio are social status (3), the age difference between husband and wife (4), time of insemination within the cycle, birth order, certain hormonal treatments and age of the parents (5,6). Because excellent statistics are available in Finland, meticulously kept in church records and subsequently by Statistics Finland (founded in 1865), several of these hypotheses can be readily tested by accessing one of the longest nationwide time-series data collections available in the world.

Methods

To test time trends in Finland, we analyzed the data [from Statistics Finland (7)] on all newborn babies born between 1751 and 1997. We analyzed the proportion of male newborn infants in Finland between 1751 and 1997 by linear regression. We determined and analyzed 9-year running averages for male infants born through 1904 and 5-year running averages for male infants born in 1905 and later. The number of births per year varies from 20,519 in 1751–1760 to 104,716 in 1946–1950. Data on stillbirths are available from 1861 (2.98% in 1861–1870, 0.4%

in 1991–1995) and are available for males and females from 1921. Even though the rate of stillbirths has dramatically decreased, the proportion of males among stillbirths has remained constant in Finland throughout 1921–1995 [0.566 ± 0.007 (mean ± standard deviation); range 0.556–0.579]. Assuming the same proportion of male stillbirths, the proportion of male live births plus stillbirths was calculated for 1861–1920. The proportion of males among children born to married Finnish couples during 1990–1997 were correlated (weighted least-squares regression, SPSS for Windows; SPSS, Chicago, IL) to father's age, mother's age, the age difference between husband and wife, and birth order of the child, based on the files of Statistics Finland (7).

Results

The proportion of male live births increased from the year 1751 to approximately 1920, with an overall decrease in trend thereafter (Figure 1). The sex ratio peaked during and after World War I and World War II. Another brief rise in the proportion of male births was observed in the early 1970s.

Data on stillbirths are available from 1861 and separately for males and females from the year 1921. Even though the rate of stillbirths has dramatically decreased in Finland, the proportion of males among stillbirths has remained constant throughout the period 1921–1995. Assuming the same proportion of stillbirths, we estimated the

proportion of male live births plus stillbirths for 1861–1920. Even after applying this correction, there was a clear increase in male to female ratio during 1861–1920 (Figure 1).

Data on young mothers was available from 1921, rendering it possible to test the correlation of maternal age to historical trends in sex ratio. The proportion of mothers < 25 years old increased from 0.251 in 1921–1930 to 0.433 in 1961–1970, and decreased thereafter to 0.196 in 1991–1995. The 1960s peak was not associated with any increase in male proportion (Figure 1).

To identify potential explanations, we analyzed all births to married couples in Finland from 1990 to 1997 for child sex ratio. There was no correlation of male proportion with paternal age (Figure 2A). We repeated the analysis for the sex ratio of the first-born child to exclude the possible effect of birth order. In this group, there was also no correlation between male proportion and paternal age (Figure 2B).

We also found no correlation between the proportion of males and maternal age (Figure 2C) or the age difference between parents (Figure 2D). When we analyzed all Finnish children born from 1990 to 1997, the mother's parity was slightly correlated with a decrease in the proportion of males (Figure 3).

Discussion

Factors that are believed to affect the male to female ratio are time of insemination within the cycle, birth order, certain hormonal treatments, and age of the parents (5,6). The present results challenge some of these assumptions at the population level. Maternal or paternal age or age difference between father and mother showed no effect. Birth order cannot account for the historical changes because birth rate decreased steadily from 4.5% in 1751 to 2.5% in 1920; in 1996 the birth rate had reduced further to 1.2% (7).

Hormonal treatments were not available in the early 1900s, and only the introduction of birth control preparations could have led to

Address correspondence to T. Vartiainen, National Public Health Institute, Division of Environmental Health, P.O. Box 95, FIN-70701 Kuopio, Finland. Telephone: 358-17-201 346. Fax: 358-17-201265. E-mail: terttu.vartiainen@ktl.fi

We thank J. Pekkanen for useful discussions and E. MacDonald for checking the English language.

Received 9 March 1999; accepted 27 May 1999.

extensive population exposure. Combination pills were first registered in Finland in 1961, and they became popular during the 1960s. Clomiphene was first registered in 1965 and was used to some extent to induce ovulation in the treatment of infertility. In principle,

these preparations could have had some contributory effect during the subsequent decades. It is of interest in this respect that the peak sex ratio of 1972–1973 (Figure 1) coincides with a temporarily reduced birth rate (1.27% in 1972 and 1.22% in 1973). At the

same time, the proportion of first-born children among all children born was high (50.6% in 1971–1975 as compared with 35.5% in 1960 and 40.1% in 1981–1985) (7), when members of the large post-war generation of the late 1940s and early 1950s were starting their own families, and methods for limiting the number of births in the family had become widely available.

The present data do not support the hypothesis that agricultural or industrial environmental estrogens play any significant role because the decrease in male to female ratio precedes the plausible exposure by several decades. Until World War II, Finland was an agricultural country using only traditional production methods and importing few food items. Both industrial development, as indicated, for example, by energy use (7) and its associated pollution, and the use of agricultural chemicals began to increase around 1950, but the trend intensified as late as 1960–1970 and peaked in 1980 (Figure 1, inset). After 1980, the use of agricultural chemicals decreased (8). Pollution of waterways by the forest industries, by far the most important group of industries in Finland until recent years, can be traced in the bottom sediments of the Gulf of Finland in the Baltic Sea (9); the historical record of polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDDs/PCDFs) in sediments is similar to that of pesticide use: there was some increase in the 1950s, a steep increase in the 1960s and early 1970s, and a decrease after the early 1980s (10). Exposure to PCDDs/PCDFs and polychlorinated biphenyls (PCBs) in Finland is primarily from consumption of fish, notably Baltic herring (11). Concentrations of PCDDs/PCDFs and PCBs in fish peaked in the 1970s (12). There was no decrease in the proportion of males during that period; in fact, there was a transient increase (Figure 1). In Sweden, Norén and Meironyté (13) observed a decrease in various persistent chemicals (DDT, PCBs, dioxins, hexachlorobenzene) in breast milk after a peak around 1970.

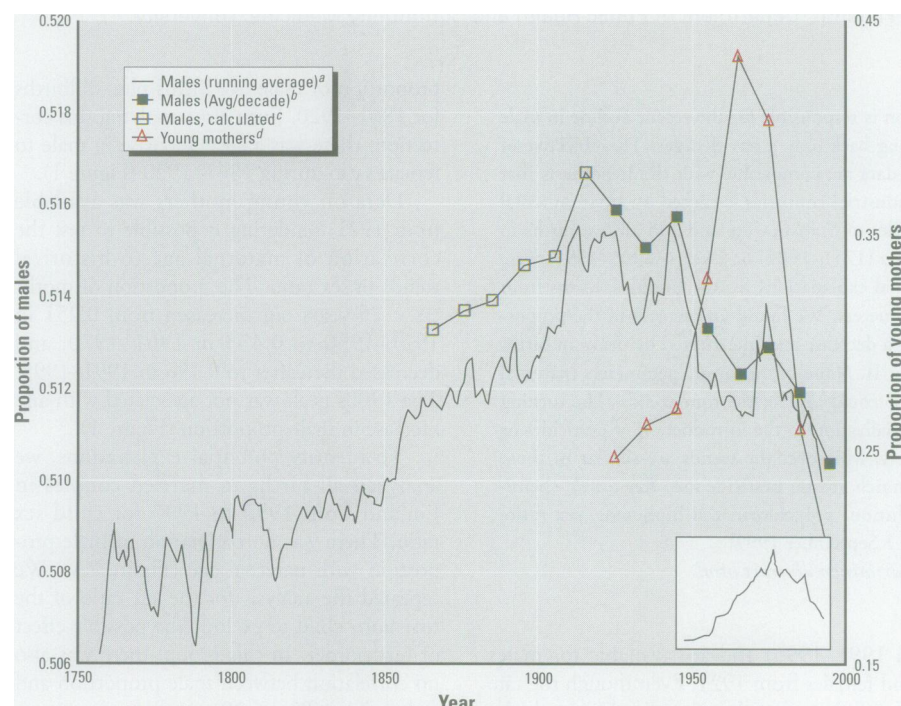


Figure 1. Proportion of males among newborn infants in Finland between 1751 and 1997. The inset [from Hynninen and Blomqvist (8) with permission from *Kemia-Kemi*] shows sales of pesticides as active ingredients in Finland; the peak in 1980 was 2,500 tons. Avg, average.

^aNine-year running average for 1751–1904 and 5-year running average for 1905–1997 (both the increase and the decrease in the overall trends before 1920 and after 1921 are statistically significant at $p < 0.001$, linear regression). ^bData on stillbirths were included for 1921–1997 (proportion of males, with live births and stillbirths together; average per decade). ^cCalculated stillbirths were included for 1861–1920 (see “Methods”). ^dProportion of young mothers (< 25 years of age).

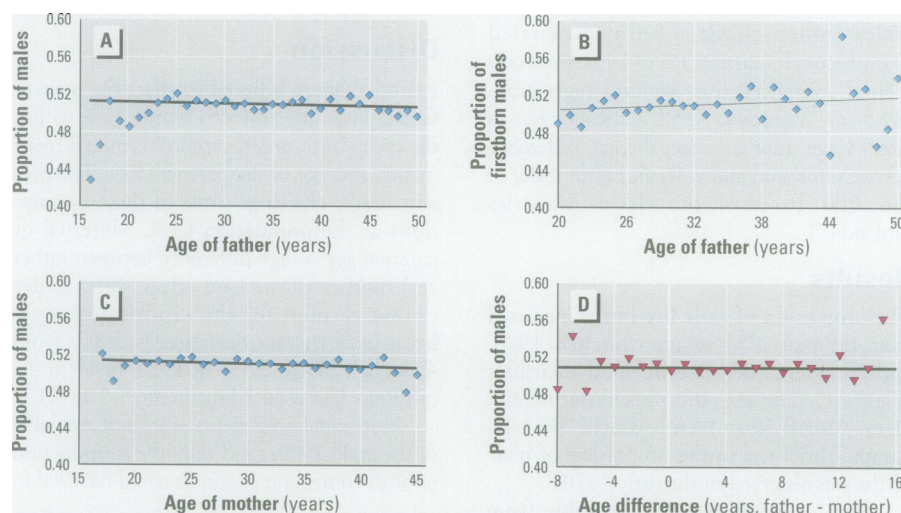


Figure 2. Proportion of males among children born 1990–1997 to married Finnish couples. (A) Correlation of the proportion of male children to father's age ($n = 362,721$; father's age 20–50 years; $R^2 = 0.039$; $p = 0.285$, weighted least-squares regression). At both extremes of parental age groups, the decreasing numbers of children cause remarkable chance variation. (B) Correlation of the proportion of male children to father's age, restricted to firstborn children ($n = 113,363$; $R^2 = 0.047$; $p = 0.244$). (C) Correlation of the proportion of male children to mother's age ($n = 363,291$; mother's age 16–47 years; $R^2 = 0.061$; $p = 0.174$). (D) Correlation of the proportion of males to the difference in age between husband and wife ($n = 324,532$; range of age difference, -8 to 15 years; $R^2 = 0.119$; $p = 0.148$).

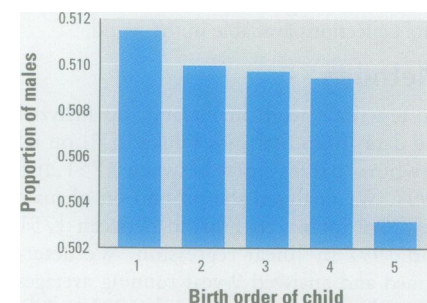


Figure 3. Influence of birth order on the proportion of male births 1990–1997 (first child 0.5114, $n = 201,727$; second child 0.5099, $n = 173,997$; third child 0.5096, $n = 86,922$; fourth child 0.5093, $n = 28,902$; fifth child 0.5031, $n = 9,004$; $R^2 = 0.860$, $p = 0.023$ by weighted least-squares regression).

These indicators of chemicalization are aggregate proxies, and it could be argued that a specific chemical may still be responsible for the changes in sex ratio. The similarity of trends of energy consumption, pesticide use, and waterway pollution by organochlorines indicates, however, that many simultaneous changes took place very rapidly during the societal and economic changes in Finland during 1950–1970. Even total automobile mileage follows the same trend (7). It is hard to imagine any environmental factor with an earlier trend in a basically agricultural country.

The decrease in the male to female ratio after 1950 is at least as prominent in Finland as in the Scandinavian countries (14) or in Central Europe (15,16), even if the general exposure to environmental chemicals in Finland was lower. Total pesticide use in 1987 in Finland was 0.8 kg/ha, as compared to 2.6 kg/ha in Denmark and 18.9 kg/ha in the Netherlands (17), and exposure to dioxins and PCBs has also been lower in Finland (18). Growth-promoting hormones have never been allowed in meat production. Sperm counts have not decreased in Finland in contrast to Central Europe (19), where some researchers have attributed a decrease to the presence of environmental estrogens.

High concentrations of dioxins, such as those released in the Seveso incident in Italy in 1976, seem to be associated with fewer males born than were expected (20). This may be a threshold effect because the phenomenon was restricted to those families suffering extremely high dioxin exposure and was likely to be associated with a marked induction of the microsomal oxidative enzymes that also metabolize steroid hormones. Heavy exposure to a mixture of PCBs and PCDDs in Taiwan was not followed by any similar major change in sex ratio (21).

Other recent analyses of the male to female ratio in Europe demonstrate clear wartime peaks, but provide little evidence for any change in baseline after the peaks (16,22,23). Among the Scandinavian countries, Norway seems to show a peak in the 1940s, but Sweden, which was not subject to war, did not (14). In the present time series, there was a long-lasting initial increase in the proportion of males in Finland from 1751 to 1920, more prominently from approximately 1850 to 1920. An increase was also found in Denmark (1), but the period of the increase was shorter and seems to have occurred later, between 1901 and 1950. Møller (1) explained this initial increase as a decrease in the rate of stillbirths with a male excess. To test this hypothesis, we analyzed data on the newborn babies, including stillbirths, but excess male stillbirths do not account for the increase in the proportion of males in Finland. Also, parents may have shown a preference for boys at earlier times, but this should lead to a higher

rate of survival and a higher sex ratio rather than the reverse.

The proportion of males in 1751 was low (~ 0.506–0.508) as compared to the earliest data available from Germany and the Netherlands in 1871 (~ 0.513) (16,22). The most common pollutant at that time was indoor smoke because chimneys were not present in all homes, especially in the eastern part of the country during the 18th and early 19th centuries. However, if smoke is a factor, tobacco smoking should have a drastic effect. Many lifestyle factors have, indeed, been suggested to lower the proportion of males, for example, maternal smoking (24), high alcohol consumption (25), exposure of males to excessive heat either occupationally or from sitting in a car (26,27), and changes in clothing styles, especially the wearing of tight underwear. These examples illustrate that there may be a number of reasons for changes in sex ratio that are at least as plausible as environmental pollution. Perhaps the role of lifestyle factors should be emphasized as it is in the causation of cancer (28). The reviews of James (25) and Bromwich (6) illustrate the great variety of explanations offered for this phenomenon, and we suspect that many of the reported causalities are, in fact, chance findings because of small groups.

It is important to the reliability of the present data that the population of Finland has been remarkably consistent over the centuries, with no major immigration taking place. The present immigrant population is only about 1.5% (7). Although much territory was ceded to the Soviet Union in 1945, the whole population from that area was translocated to other parts of the country. The Lutheran Church of Finland has been the dominating church over the entire period of observation (e.g., in 1920, 98% Lutheran, 1.6% Greek Orthodox, and 0.03% agnostic in the civil register). The church records have been used in a number of population studies; although omissions of births in the earliest years are possible (29), there is no reason to suspect systematic gender bias.

In conclusion, we were not able to confirm that chemicalization (in the sense of exposure to agricultural or industrial chemicals) is a significant source of changes in sex ratio. Family parameters did not help to explain the historical trends. The well-established wartime peaks may indicate that there is some fundamental physiologic process that responds to periods of crisis and real or potential loss of fighting males. It is unknown at present how this would be mediated (25), but it would certainly include neuroendocrinologic mechanisms and possibly behavioral changes. It cannot be excluded that the decrease in male excess might simply be related to a return to a normal level in a time of peace.

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